The occurrence of exercise-induced dynamic obstruction of the left ventricular outflow tract in patients without cardiomyopathy has recently been reported. However, it is not known if this phenomenon is a normal response to exercise in healthy adults. We studied 23 healthy adults using exercise Doppler echocardiography. We measured the left ventricular outflow velocity at rest and after maximum tolerated exercise. After a mean exercise duration of 12 min 45 s (2 min 32 s), the heart rate was 97.61 (6.71)% of the theoretical maximum. Left ventricular outflow velocity increased from 1.07 (0.18) m/s (range: 0.77-1.44 m/s) to 1.58 (0.35) m/s (range: 1.09-2.4 m/s). In healthy adults, exercise increased the left ventricular outflow velocity by 50%, though in no subject was it greater than 2.5 m/s. This observation appears to rule out the possibility that a high intraventricular pressure gradient is a normal response to exercise in healthy adults.

Key words: Exercise echocardiography. Left intraventricular pressure gradient. Left ventricle.
Baseline and post-exercise echocardiography was performed by an experienced cardiologist with a VingMed echocardiograph equipped with Super-VHS recording system and Pinnacle DV500 Plus video-digitizer, using a 2.5-3.25 MHz probe. We performed a complete standard baseline Doppler echocardiogram. Measurements were taken according to American Society of Echocardiography recommendations.\(^4\)

Immediately after exercise (30-60 s), with the volunteer in lateral decubitus, we again analyzed SLVO, transmural flow and systolic function. Exercise was taken on a Marquette Case 8000 treadmill ergometer (Marquette Medical Systems Inc., Milwaukee, US) following the Bruce protocol after 4 hours fasting, and continued until subjects presented symptoms of exhaustion or achieved maximum theoretical heart rate.

**RESULTS**

The 23 subjects were men of age 32.5±5.9 years (range, 25-45), weight 78.7±7.1 kg, height 176.6±4.9 cm, mean body mass index 25.7±2.4, and body surface area 1.94±0.09 (range, 1.74±0.13). Baseline echocardiogram data appears in Table 1. Maximum SLVO velocity at rest was 0.77±1.44 m/s, mean 1.07±0.18 m/s. Mean exercise time was 12 min 45 s±2 min 32 s after which subjects achieved a mean heart rate of 97.6±6.7% of the estimated theoretical maximum for their age. Data relative to performance is in Table 2.

Following exercise (Table 3), maximum SLVO velocity was 1.09-2.45 m/s (mean, 1.58±0.35 m/s). None of the subjects presented morphology indicating dynamic gradient or anterior movement of the mitral valve.

**DISCUSSION**

The appearance of left intraventricular gradients in patients without hypertrophic cardiomyopathy is well documented in relation to hypercontractile states, following valvular surgery,\(^10-13\) acute coronary syndromes,\(^14,15\) or dobutamine stress echocardiography.\(^16,17\) Recently, it has also been reported in relation with exercise.\(^3,13,18\) Elsewhere, we reported on a series\(^1\) that constituted a population with high incidence of hypertension and of women in which the only predictor factor of this phenomenon was left ventricular outflow tract diameter.

However, the presence of small intraventricular gradients in healthy ventricles is known. In 1980, Falsetti et al\(^19\) found 2.10±0.47 mm Hg gradients between the left ventricular apex and base using high precision micromanometers in dogs. Later, Pasipoularides et al\(^1\) also used catheters in 6 patients without valvular or ventricular abnormalities and found gradients at rest of 6.7±1.9 mm Hg, which increased to 13±2.3 mm Hg following bicycle exercise. More recently, Yotti et al\(^\ast\) have confirmed the existence of this phenomenon and the possibility of recording it using a new echocardiographic method, detecting values of 3.3±1.6 mm Hg in 20 healthy volunteers at rest.

However, little data is available on the behavior of these small “physiologic” gradients during physical exercise.\(^\ast\) In the series of 6 cases, Pasipoularides et al\(^1\) specifically studied this aspect and found that gradients

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### TABLE 1. Baseline Echocardiographic Data\(^*\)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline</th>
<th>Post-Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDD, mm/m²</td>
<td>25.4±1.9</td>
<td>21.4±2.5</td>
</tr>
<tr>
<td>ESD, mm/m²</td>
<td>15.9±1.8</td>
<td>11.1±1.9</td>
</tr>
<tr>
<td>Septum, mm/m²</td>
<td>4.42±0.46</td>
<td>3.48±0.33</td>
</tr>
<tr>
<td>LVOT, mm/m²</td>
<td>10.9±0.7</td>
<td>9.75±12.11</td>
</tr>
<tr>
<td>LVMI, g/m²</td>
<td>78.7±11.9</td>
<td>47.3±65.8</td>
</tr>
<tr>
<td>RPF, m/s</td>
<td>0.87±0.07</td>
<td>0.84±1.18</td>
</tr>
<tr>
<td>UMI, g/m²</td>
<td>38.7±10.1</td>
<td>47.3±65.8</td>
</tr>
<tr>
<td>IVT, mm/m²</td>
<td>7.0±1.9</td>
<td>7.7±1.9</td>
</tr>
<tr>
<td>Max. rate, beats/min</td>
<td>140±26</td>
<td>183±12.24</td>
</tr>
<tr>
<td>Cardiac index, L/m²</td>
<td>2.4±0.5</td>
<td>5.4±1.3</td>
</tr>
</tbody>
</table>

* SD indicates standard deviation; EDD, end-diastolic diameter; ESD, end-systolic diameter; LVOT, left ventricular outflow tract; LVMI, left ventricular mass index; IVT, integral velocity-time; UMI, left ventricular integral velocity-time; RPF, relative parietal thickness; LVMI, left ventricular mass index; IVT, integral velocity-time; LVOT, left ventricle outflow tract.

### TABLE 2. Exercise Performance Data\(^*\)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline</th>
<th>Post-Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP systolic, mm Hg</td>
<td>120±4±0.9</td>
<td>151±2±16.8</td>
</tr>
<tr>
<td>AP diastolic, mm Hg</td>
<td>75±6±0.9</td>
<td>74±6±8</td>
</tr>
<tr>
<td>HR, beats/min</td>
<td>73±11±15</td>
<td>180±11±12.24</td>
</tr>
<tr>
<td>% maximum theoretical HR</td>
<td>97±11±6.7</td>
<td>97±11±6.71</td>
</tr>
<tr>
<td>Metabolic Equivalent</td>
<td>14±6±2.39</td>
<td>14±6±2.39</td>
</tr>
<tr>
<td>Double product</td>
<td>25±9±2±7.48</td>
<td>25±9±2±7.48</td>
</tr>
</tbody>
</table>

* SD indicates standard deviation; HR, heart rate; AP, arterial pressure.

### TABLE 3. Hemodynamic Parameters Before and After Exercise\(^*\)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline</th>
<th>Post-Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ejection fraction, %</td>
<td>74±7±3.8</td>
<td>84±9±4.8</td>
</tr>
<tr>
<td>LVOT, mm/m²</td>
<td>19±6±3.2</td>
<td>22±6±5.0</td>
</tr>
<tr>
<td>Cardiac index, L/m²</td>
<td>4.6±1.1</td>
<td>10.5±2.5</td>
</tr>
<tr>
<td>Cardiac index, L/m²</td>
<td>2.4±0.5</td>
<td>5.4±1.3</td>
</tr>
</tbody>
</table>

* SD indicates standard deviation; IVT, integral velocity-time; LVOT, left ventricle outflow tract; V\(_{max}\), maximum velocity.
doubled with submaximal physical exercise of decubitus pedaling. Various studies\textsuperscript{1,3,5} related to the effects of exercise show an increase in SLVO velocities during exercise and, although they studied different populations, none of them found a two-fold increase in flow velocity at rest. In our series of 23 healthy volunteers, SLVO flow velocity exceeded 1.07±0.18 m/s (range, 0.77-1.44) at rest, reaching 1.58±0.35 m/s (range, 1.09-2.45) after exercise, which represents a 50% increase. These data suggest that, in the post-exercise treadmill echocardiogram, SLVO velocities of 1.58±0.35 m/s, with a range of 1 up to 2.4 m/s can be considered normal.

We conclude that maximum exercise tolerated by healthy adults increases left ventricular outflow velocity by up to 50% but that in no case does it reach 2.5 m/s. Although this does not entirely exclude the possibility that elevated intraventricular gradients may be a habitual response to exercise in healthy adults, it does make this highly unlikely.

Limitations of the Study

In addition to the sample size, this study is limited by the fact that the SLVO velocities were recorded immediately after exercise and not during maximum exercise. This is inevitable with treadmill exercise but could lead to an underestimate, given the tendency to diminish in the minutes after ceasing exercise, despite the fact we recorded high levels of exercise (97.6±6.71%). This series only included young men. Although this implies a bias in terms of gender and age, we considered on this study design to facilitate optimization of echocardiographic images (as pectoral anatomy is easier in men) and to attain high levels of exercise. Moreover, the appearance of dynamic obstruction during exercise has not been linked with gender\textsuperscript{6}.

Use of the simplified Bernoulli equation to calculate intraventricular gradients in these cases is incorrect due to the absence of anatomic obstruction and the relatively low velocities; consequently, it may be more adequate to express results in terms of velocity without transforming this into gradient, or rather, to apply the recently proposed method of measurement with color M-mode Doppler\textsuperscript{6}.

REFERENCES

1. Petroto J, Montecatini L, Caстро-Beníus A. Lodato subaortico: obstruc-
5. Pasqualin D, Margo JP, Miller WP, Craig WE. Nonobstructive-
6. Yotti R, Benrezic J, Antonuci IC, Rojo-Arávez JL, Aller C, Sil-
7. Yotti R. ¿Qué significa tener un gradient de presión intraven-
11. Melero JM, Rodríguez I, Such M, Portac C, Otda E, Left ventri-
12. Bartunek J, Jyljä KT, Rodriguez AC, van Schaerenck E, Mortier L, de Broste B. Abnormal systolic intraventricular flow velocities af-
ter valve replacement for aortic stenosis. Mechanisms, predictive-
13. López Ayerbe J, Evangelista Maupu A, Armada Romero E, Ma-
tesi González M, González Mejía MT, García del Castillo H, et al. Predictive factors of abnormal dynamic intraventricular gra-
14. Haley HH, Smilc LA, Tjamp AJ, Ommen SR, Oh JK. Dynamic left ventricular outflow tract obstruction in acute coronary syn-
15. san Roman Sanchez D, Mechu O, Jiménez F, Rodríguez JC, Nie-
16. Petikka PA, Ono JK, Bailey KR, Nichols RA, Monahan KH, Taj-
induced left ventricular obstruction during stress echocardi-
ography: a higher hemodynamic responsiveness to dobutamine.
18. Meimoun P, Benali T, Sayah S, Luyx-Borre A, Maitre B, Tri-
19. Levy EL, Pines A, Dozy Y, Rombusch HH, Tenenbaum A, Fis-
man EZ. Exercise-induced aortic flow parameters in early post-
257-60.
20. Stoylen A, Wulfsof U, Storlalch S. Left ventricular mechanics du-
rine exercise: a Doppler and tissue Doppler study. Eur J Echocar-